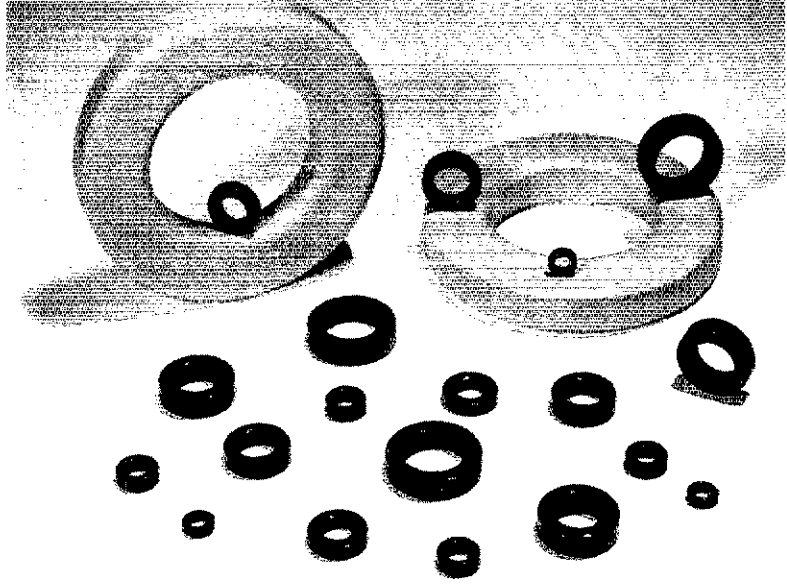
Toroids—Some Practical Considerations



Are you confused when it comes to using toroids? The tips given in this article may simplify your next project.

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Do you work with toroidal inductors and transformers? Are you confused about some of the practical aspects that relate to these useful devices? If your answers to these questions are yes, you're not unique among your experimenting peers!

Numerous articles concerning toroidal coils and transformers have appeared in *QST* over the years, and *The ARRL Handbook* includes a section on the application of toroids. But some of the application methods are not highlighted in the average text that treats these devices. This article focuses on the day-to-day questions that I receive about toroids and how to use them.

A Short Review of Toroid Advantages

Why should we use toroids in place of air-core or slug-tuned coil forms? Foremost of the reasons is cost, at least for experimenters. Small toroid cores are less expensive than good quality ceramic coil forms—especially those that contain adjustable powdered-iron or ferrite slugs. Another benefit from the use of toroids is that shield cans aren't necessary in order to isolate the toroidal coil from adjacent components. Toroids have an inherent self-shielding property. Specifically, the field from a toroidal inductor is pretty much self-contained. This means that radiation from the coil or transformer is minimal compared to a solenoidal coil that has an air or slug core. No metal shield can or shield compartment is needed to prevent a toroidal coil from causing stray coupling to adjacent coils or components.

A tuned circuit that contains a toroidal coil will generally have a high Q (quality factor), if the correct core material is chosen. Some multilayer slug-tuned coils have relatively low Q factors (100 or less). High Q is important in VFO circuits and in some RF filter units.

Broadband transformers are made easily when we use magnetic cores, with ferrite being the most common of the cores for this purpose. Equivalent performance over a wide range of frequency is not possible when we use air-core inductors for the windings.

Finally, toroids are usually more compact than their conventional equivalents. This helps us to design and build miniature amateur equipment.

Choosing the Proper Core

I am asked frequently, "Should I use ferrite or powdered-iron toroids?" There is no simple answer I can offer. Powdered-iron cores are less prone to saturation at a particular power level (heating and changes in core permeability) than are ferrite cores of equivalent size (cross-sectional area). Unfortunately, a same-size powdered-iron core (compared to a ferrite one) has substantially less permeability. This means that considerably more turns are needed for a given inductance when we use powdered iron. Too large a number of turns can spoil the performance of a broadband transformer. It is for this reason that ferrite rods and toroids are found in most balun and other broadband RF transformers. A concise treatment of this subject is given in Jerry Sevick's book.[1]

Ferrite and powdered-iron cores are rated for optimum Q versus operating frequency. The catalog from Amidon Associates, Inc contains tables that specify the frequency limits for both types of core material.[2] Table 1 offers a rule-of-thumb guide that will assist you in selecting a suitable core for narrow-band tuned circuits in the MF and HF ranges. The cores specified are popular ones that are sold by Amidon Associates, Inc, Palomar Engineers and RadioKit.[3,4,5]

The recommendations of Table 1 are approximate, and are based on personal experience and preference, respective to safety margins. The Q-versus-frequency listings are for narrow-band tuned circuits. Smaller and larger toroid cores are available. Those listed are the most popular sizes among radio amateurs. The powdered-iron cores are manufactured by Micrometals Corp, and the ferrite ones are produced by Fair-Rite Corp. Permeabilities for all of these cores are listed in the Amidon Associates catalog.

The power ratings given in Table 1 are for low-impedance harmonic filters and broadband transformers, and do not apply to narrow-band tuned circuits. Greater power limits may be possible under some conditions. The high RF voltage associated with tuned high-impedance resonators reduces the maximum ratings in watts per given core size. This is discussed in the *Ferromagnetic-Core Design & Application Handbook*[6] and in *The ARRL Handbook*. The power ratings of magnetic cores are based on ac and dc voltage in the windings, the number of coil turns, and on other factors. Equations for determining the correct core size are found in the *Ferromagnetic-Core Handbook* and *The ARRL Handbook*.

The Q ratings in Table 1 are for optimum Q versus operating frequency. Acceptable performance is available above and below the listed frequencies (see Amidon Associates charts). You may use any of the toroids in Table 1 at frequencies below the optimum Q notations. You should be aware also that the higher the recommended operating frequency, the lower the core permeability. Most broadband trans-

[1]Notes appear on p 36.

Table 1

Guide to Selection of Cores for Narrow-Band Tuned Circuits

Amidon Core no.	Material	Optimum Q V Max Freq, MHz	Core OD (inches)	Suggested Max RF Power (Low-Z Circuits), Watts
T-37-3 (gray)	Iron	0.6	0.37	5
T-37-2 (red)	Iron	4	0.37	5
T-37-6 (yellow)	Iron	12	0.37	5
T-37-10 (black)	Iron	40	0.37	5
T-37-12 (grn/wh)	Iron	90	0.37	5
T-50-3 (gray)	Iron	0.6	0.50	25
T-50-2 (red)	Iron	4	0.50	25
T-50-6 (yellow)	Iron	12	0.50	25
T-50-10 (black)	Iron	40	0.50	25
T-50-12 (grn/wh)	Iron	90	0.50	25
T-68-3 (gray)	Iron	0.6	0.68	75
T-68-2 (red)	Iron	4	0.68	75
T-68-6 (yellow)	Iron	12	0.68	75
T-68-10 (black)	Iron	40	0.68	75
T-68-12 (grn/wh)	Iron	90	0.68	75
FT-37-43	Ferrite	1	0.37	1
FT-37-64	Ferrite	4	0.37	1
FT-37-61	Ferrite	10	0.37	1
FT-37-63	Ferrite	25	0.37	1
FT-37-67	Ferrite	80	0.37	1
FT-37-68	Ferrite	180	0.37	1
FT-50-43	Ferrite	1	0.50	5
FT-50-64	Ferrite	4	0.50	5
FT-50-61	Ferrite	10	0.50	5
FT-50-63	Ferrite	25	0.50	5
FT-50-67	Ferrite	80	0.50	5
FT-50-68	Ferrite	180	0.50	5
FT-82-43	Ferrite	1	0.82	25
FT-82-64	Ferrite	4	0.82	25
FT-82-61	Ferrite	10	0.82	25
FT-82-63	Ferrite	25	0.82	25
FT-82-67	Ferrite	80	0.82	25
FT-82-68	Ferrite	180	0.82	25

formers for the MF and HF spectrum are wound on no. 43 ferrite material (850 permeability). Some broadband transformers (for HF) are wound on no. 61 material (125 permeability). The larger the core, irrespective of the permeability, the fewer turns needed for a specified inductance. Cores may be stacked atop one another to increase the effective cross-sectional area. This permits fewer turns and greater power-handling capability. You may use epoxy cement to affix the cores to one another.

Winding Information

Toroid and rod cores that are used where high values of RF and dc voltage are present should be wrapped with 3M glass tape or Teflon tape before adding the windings. This insulates the windings from the core material, which helps prevent arcing between the windings and the core. I use three layers of plumber's thread-seal tape for core wrapping. It is inexpensive, readily available, and made of Teflon.

I am asked many times, "How should the link (smaller winding) be placed on a toroid, respective to the larger winding?" I always place the larger winding on the core first. It is wound to occupy approximately 300° of the core (leave a small gap between the ends of the winding). The smaller winding is added next. I wind it over the entire area of the larger winding (same polarity or sense), when possible, for broadband transformers. Sometimes this is impractical, especially if the small winding has only one or two turns. In this case, I wind the link over ¼ or ⅓ of the main winding, at the low-impedance end of the large winding. I always place the link over the low-impedance end of the larger winding when I construct narrow-band toroids. This helps to reduce unwanted capacitive coupling between the windings.

I have also been asked, "Do you wind the wire through the toroid or around the perimeter?" The answer is *definitely* "through the core!"

The Right Number of Toroid Turns

Each core you use has an A_L factor. This relates to the core permeability and the cross-sectional area. When the desired inductance is known, you may calculate the necessary turns to obtain the required inductance. The A_L factor is based on a specific number of turns for a given inductance. The equation for powdered-iron cores is

$$N \text{ (turns)} = 100\sqrt{L_{\mu H}/A_L} \qquad \text{(Eq 1)}$$

where

N = number of turns

$L_{\mu H}$ = required inductance

A_L = specified value for the core being used

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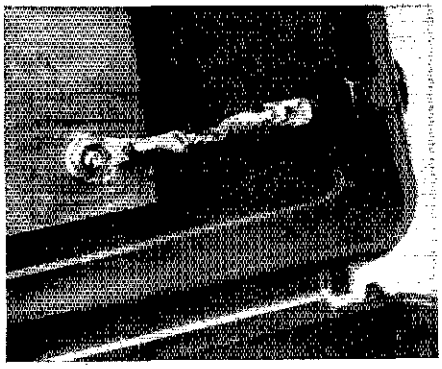

Fig 3—Ground-radial banana jack to ground-plate connection. Phone or phono jacks could also be used. See text.

or 6-32 machine screws. At the center point of the plate, make a 1-inch hole with a hole saw or drill. Smooth and deburr the holes.

Center the drilled plate in the carrying-case cover. (Be sure to position the two RF cable holes on the side of the case that you wish the RF cable to exit on.) Mark the four corners and two cable holes on the carrying case cover. Using the same drill you used on the plate, drill these six holes in the case cover. Attach the ground plate to the case cover using ¼-inch-long, no. 4- or 6-32 flat-head machine screws, washers, solder lugs and nuts. Note: If you countersink the cover holes to keep the cover surface flat, be careful not to overdrill the hole. If you choose not to countersink the holes, use a small amount of clear RTV sealant on the exposed screw heads to help avoid marring surfaces.

The next step is to install the ground-radial jacks. Drill four holes in the sides of the carrying-case cover large enough to mount banana jacks. Install four banana jacks on the case cover. Using a short length of no. 12- or 14-gauge stranded wire or braid, solder the banana jacks to solder lugs, then attach these lugs to the ground plate mounting screws (see Fig 3).

Cut four 6-inch radials from 1/16-inch thick round brass rod (available at hobby stores) and solder a banana plug to each rod. Plug the radials into the banana jacks and bend the rods so that they are at a 45° angle as shown in Fig 1.

Inspect the antenna you are going to use, determine how large a hole must be made in the carrying-case cover and make that hole. (Be sure that you have sufficient clearance to prevent shorting the coax center conductor against the ground plate.) Expose enough coax ground braid and center conductor and install solder lugs to each. Install the coax ground-braid lug to the ground plate connection and secure the coax cable to the ground plate with a cable clamp. See Fig 4.

Once the coax has been secured to the ground plate, route the cable to the exit point on the carrying case. Mark this point. Then use a small round file to make a notch on the case cover large enough to fit the coax snugly as shown in Fig 1. Install the

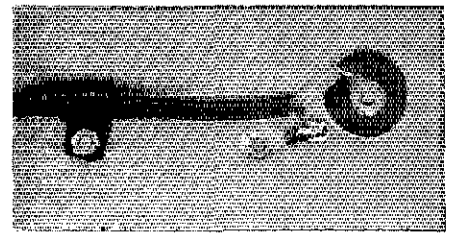

Fig 4—The coaxial-cable connection points on the ground plate. A screw-mount vertical antenna element is used in this model, but a BNC connector would allow use of popular 1/2- or 5/8-λ portable 2-meter antennas.

telescoping antenna element, connect the coax center conductor to the antenna and construction is complete.

Operation

The 2-meter FM system setup is simple: Plug in the radials, connect the hand-held to the vertical antenna via an SWR meter, extend the vertical element approximately 19 inches and have at it! When you tune the antenna, be sure to mark it for your favorite frequencies or subbands.

I have found this carrying case very handy at home and on the road. The next time you clean your shack, take a careful look at that "junk" before you throw it away—you might have "The Case of a Portable Hand-Held Transceiver"!

Toroids—Some Practical Considerations

(continued from page 33)

Ferrite-core inductances are calculated from

$$N \text{ (turns)} = 1000 \sqrt{L_{mH}/A_L} \quad \text{(Eq 2)}$$

You may use Eq 2 for microhenry values by retaining the 1000 factor and converting microhenrys to millihenrys. For example, if you want to wind a 100-μH coil on a ferrite toroid, use 0.1 mH in Eq 2 for the desired 100-μH value. Similarly, should you need a 10-μH inductor, use 0.01 mH in Eq. 2. The Amidon catalog contains A_L factors for ferrite and powdered-iron toroids.

Some Final Touches

Try to use a wire gauge that permits a close-wound toroid. The Amidon catalog lists the number of turns possible (single-layer winding) for various core sizes versus wire gauge. If you use smaller wire, try to space the turns evenly apart to occupy 300° of the core area. Generally speaking, spaced turns will result in slightly less inductance than the calculated value from the A_L equation. Compressing the turns will increase the inductance; spreading them will decrease the inductance.

I like to secure my toroid windings, once they are in place. This may be done by coating them with polystyrene Q Dope or polyurethane lacquer.

You may wish to secure the completed toroids on a PC board. I avoid flat mounting when I use one side of a double-sided board as a ground plane. The proximity of the turns to the copper ground plane introduces unwanted stray capacitance across the toroid winding, which in turn increases the apparent inductance of the winding. I do not object to flat mounting when I use single-sided PC boards.

Vertical mounting of toroids is practical when you want to reduce the overall area of your board. This is a space-saving technique. Vertical mounting calls for gluing the coil or transformer to the PC board. This prevents lead flexing, which can cause failure. I use a quick-setting epoxy cement for securing my vertical toroids. A generous blob of cement is placed under the toroid, which is usually about 1/16 inch above the PC board. Normally, this is at the gap area of the toroid winding. Therefore, the epoxy cement does not cover the winding.

You may also cement flat-mounted toroids to a PC board. Use a small drop of epoxy cement at only two points where the toroid rests against the PC board. The two points should be 180° apart.

I hope these tips are helpful to you. Be sure to check the book references for more detailed information about toroidal coils and transformers.

Notes

[1]J. Sevick, *Transmission Line Transformers*, 1st ed. (Newington: ARRL, 1987).
[2]Amidon Associates, Inc, 12033 Otsego St, N Hollywood, CA 91607, tel 818-760-4429.
[3]See note 2.
[4]Palomar Engineers, PO Box 455, Escondido, CA 92025, tel 619-747-3343.
[5]RadioKit, PO Box 973, Pelham, NH 03076.
[6]M. F. (D.) DeMaw, *Ferromagnetic-Core Design & Application Handbook*, 1st ed. (Englewood Cliffs, NJ: Prentice-Hall, Inc, 1981).